RT20 Program SEE and TID Data (to date): KU040 vs. KU060 x-sections

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20nm UltraScale results – summary to date

	Protons > 40 MeV	Heavy-ions	SEL	SEFI	TID
Max. particle or ion energy	64 MeV / > 10MeV [1]	1 - 58 MeV.cm^2/mg	58 MeV.cm^2/mg		100k Rad (Si) [2]
Facility	CNL / LANSCE	LBNL	LBNL	LBNL / CNL	Vanderbilt University
Test Results (Production XC parts)	2.6 x 10^{-15} cm^2/bit	1E-8 upset/bit/day	NO events @ 125^{0}C	TBD	Avg. 7% increase in ICCINT No performance degradation

- Summary includes all data to date
- 4 major particle tests planned for 20nm RT
  - Proton SEU, SEL & 1st pass heavy-ion SEU/SEL completed at CNL, LANSCE and LBNL respectively
  - X-Ray TID measurements at Vanderbilt University using the ARACOR® XRAY machine
- SEL & SEU primarily performed on XCKU040 [3]
  - Additional HW resources will be required for SEFI testing & uncorrectable events rate for heavy-ions > 14 MeV.cm^2/mg

[1]. Xilinx UG116 report
[2]. 100k Rad adequate for most applications
[3]. Common architecture & Design for other Ultrascale devices

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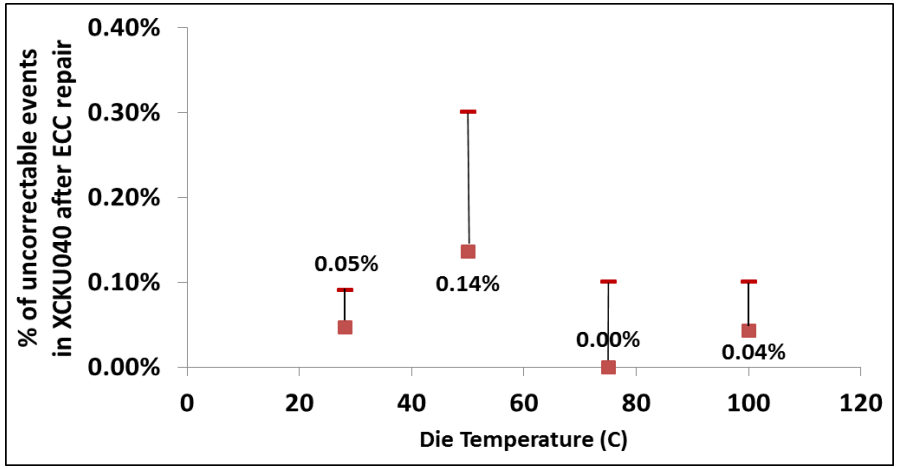
SEU and SEL Results

Terrestrial environments normalized to NYC sea level

Device	Type	Neutron & Proton FIT /Mb [1,2]	Alpha FIT /Mb [2]	Thermal neutron FIT /Mb [2]
XCKU040 / XCKU060	CRAM	33 / 34	20	0.5
XCKU040 / XCKU060	BRAM	58 / 56	40 (Estimate from foil)	1.0

- Above data applies to both KU040 & KU060
  - Same IC design and technology
- > 99.9% of CRAM events are correctable
  - At both Room and High Temperature
- 100% of BRAM events are correctable
- No SEL observed at temperatures up to 125°C
  - Total fluence applied ~ $2x10^{12}$ p /cm^2



[1]. 64MeV Proton saturated cross section
[2]. ± 20% @ 90% Confidence Interval
For SEU cross-section please refer to UG116

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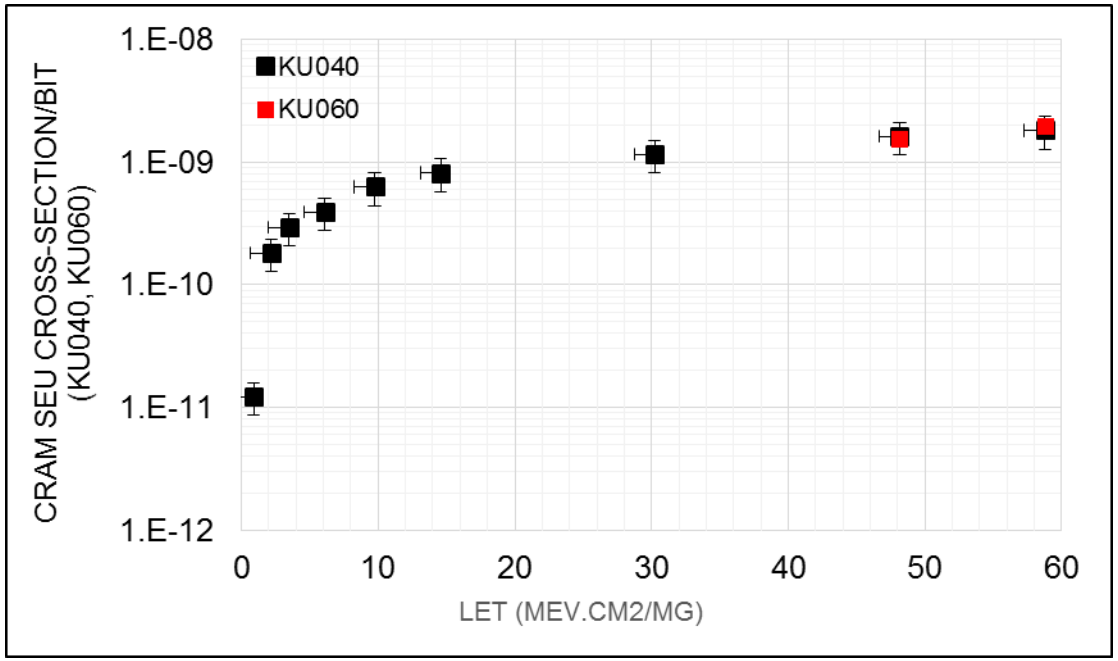
Heavy-Ion SEU and SEL Results: KU040 vs. KU060



	SEL cross-section per device					
LET	KU040	KU040 (Error bar @ 90% cl)	KU060	KU060 (Error bar @ 90% cl)	VU095	VU095 (Error bar @ 90% cl)
0.89	0.00E+00	7.50E-08				
2.19	0.00E+00	7.50E-08				
3.49	0.00E+00	7.50E-08				
6.09	0.00E+00	7.50E-08				
9.74	0.00E+00	7.50E-08				
14.59	0.00E+00	7.50E-08				
21.74	0.00E+00	7.50E-08				
30.23	0.00E+00	7.50E-08				
34.73	0.00E+00	7.50E-08				
48.15	0.00E+00	7.50E-08	0.00E+00	1.50E-07		
58.78	0.00E+00	7.50E-08	0.00E+00	1.50E-07	0.00E+00	4.29E-08
85.76	0.00E+00	7.50E-08				

- CRAM ~ 1 x 10^{-8} upset /bit /day
  - Total fluence of 1 x10^{7} ions /cm^2 for LET ≥ 48 MeV.cm^2/mg
  - Data collected for both KU040 and KU060; FPGAs thinned at ~ 50um
- NO SEL event observed @ 125°C at LET up to 85 MeV.cm^2/mg [1]
  - Total cumulated fluence of 1 x10^{7} ions /cm^2; Data collected for KU040, KU060 and VU095
- KU040 and KU060 beam test results show good correlation within error bars
  - As expected – common architecture, identical design blocks and layout used across Kintex & Virtex Ultrascale devices

[1]. Maximum LET for LBNL 88” cyclotron for 10 MeV cocktail due to ion source availability limitation

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TID Test Results (Example data for KU040)

Dose rate	Dose / step	Additional wait time between steps (min.)	Junction Temp (^{o}C)	Total dose kRad (Si)	ICC-INT (pre-dose)	ICC-INT [1] @ Total dose	Delta ICC	ICC-INT after 1 week	Delta Performance	Comments
4k Rad /min	4k Rad	5	~ 40^{0}C	110	2.21	2.40	9%	Same as pre-dose	<< 1%	< 10% increase in leakage current; independent of dose rate Part fully recovered after 1 week at Room Temperature (unpowered)
7k Rad /min	7k Rad	0	~ 40^{0}C	110	2.22	2.43	9%	Same as pre-dose	<< 1%	

[1]. At 100 kRad Tj ~ 40^{o}C

- < 10% increase in leakage current @ 110k Rad (Si)
  - Independent of dose rate
  - Leakage data corrected to same die temperature
- Full recovery in leakage after > 1 day at room temperature
  - Held at ~31^{0}C; unpowered

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Next steps

	Proton SEU / SEL	Heavy-ion SEU / SEL	SEFI	TID
Max particle or ion energy	0 - 64 MeV	1 - 80 MeV.cm^2/mg		≥ 100 krad (Si)
Facility	CNL / TRIUMF	LBNL	CNL / LBNL	DMEA / Cobham
Goal	Estimates for LEO	w/ ECC (SEM IP enabled) SEL study @ High LET	Estimates for LEO & GEO	Validate X-Ray results

- Additional testing planned for KU060 (and/or KU040)
  - Extend data set to LEO (and GEO)

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Appendix:

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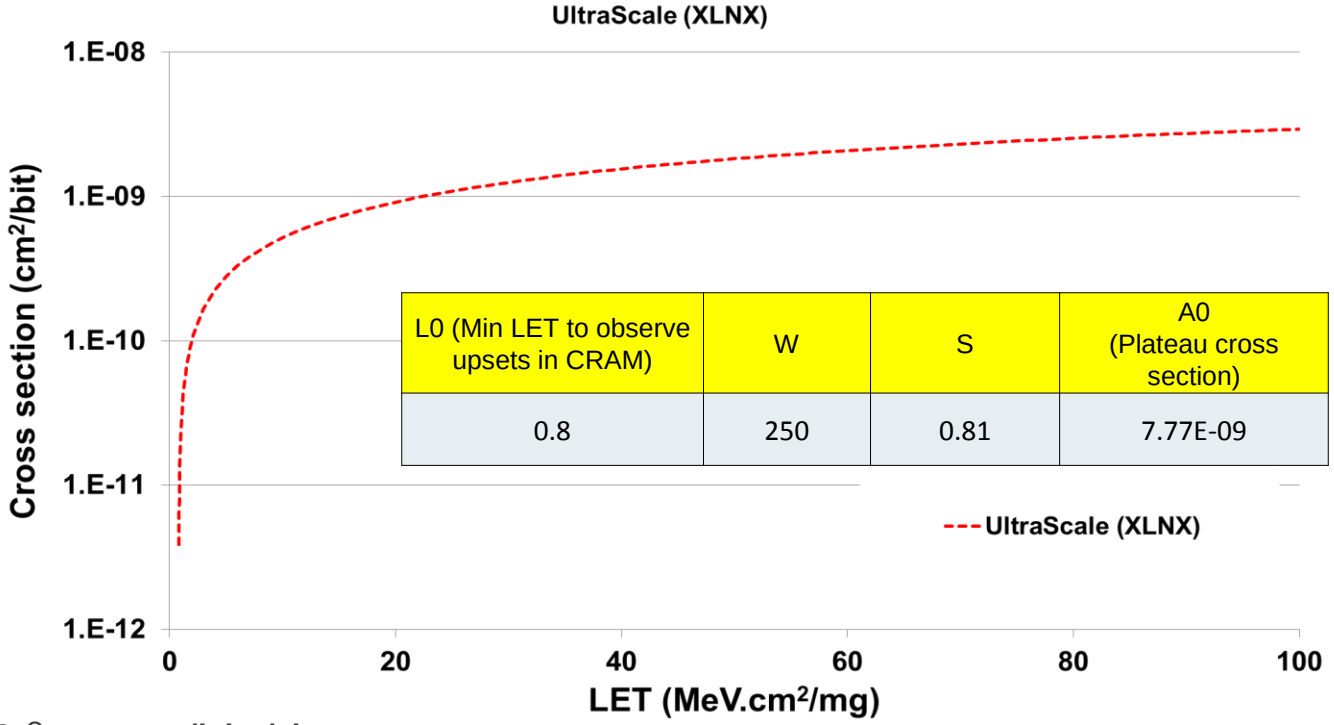
Heavy-Ion SEU and SEL Results



L0 (Min LET to observe upsets in CRAM)	W	S	A0 (Plateau cross section)
0.8	250	0.81	7.77E-09

- CRAM ~ 1 x 10^{-8} upset /bit /day
  - Total fluence of 1 x10^{7} ions /cm^2 per run
- NO SEL event observed @ 125^{o}C at LET up to 58 MeV.cm^2/mg [1]
  - Total fluence of 1 x10^{7} ions /cm^2 per run
  - Data collected for both KU040 and KU060
- Future investigation
  - uncorrectable event rate for LET > 14; with scrubbing (Xilinx SEM-IP) enabled

[1]. Maximum LET for LBNL 88” cyclotron for 10 MeV cocktail due to ion source availability limitation

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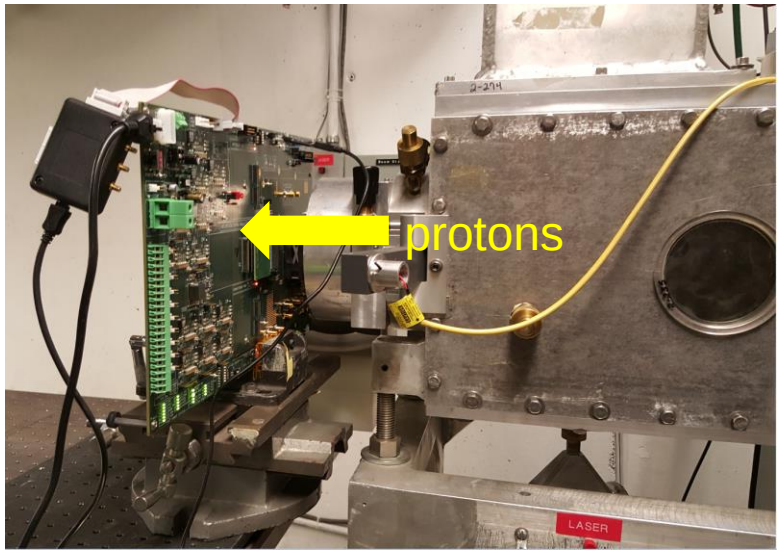
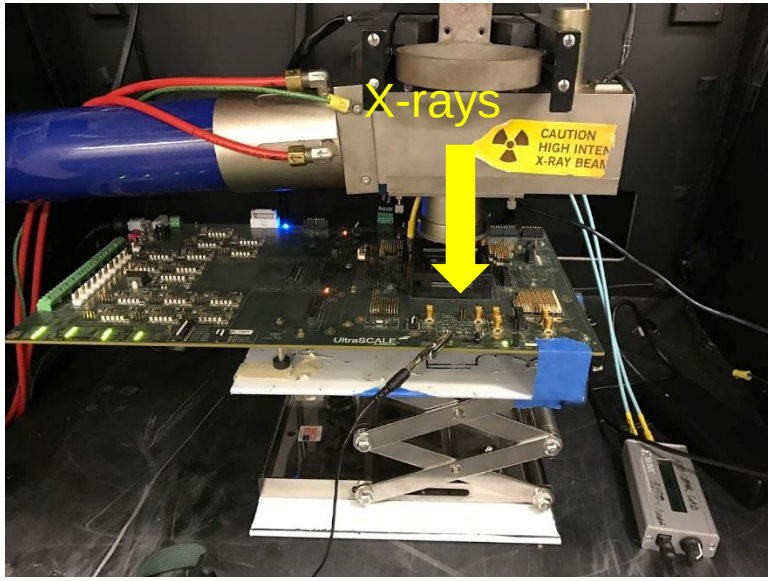
20nm UltraScale SEU / SEL / TID test set-up

- DUT: XCKU040 / XCKU060 commercial device
  - KU060 & KU040 share the same IC design
- DUT mounted on AFX-1156 board
  - Kapton heater tape used for elevated temperature testing
- Monitoring device through Vivado SW
  - Program FPGA (static patterns)
  - Monitor junction temperature (SysMon)
  - Readback bitstream
- Test setup described here is customized for each test facility





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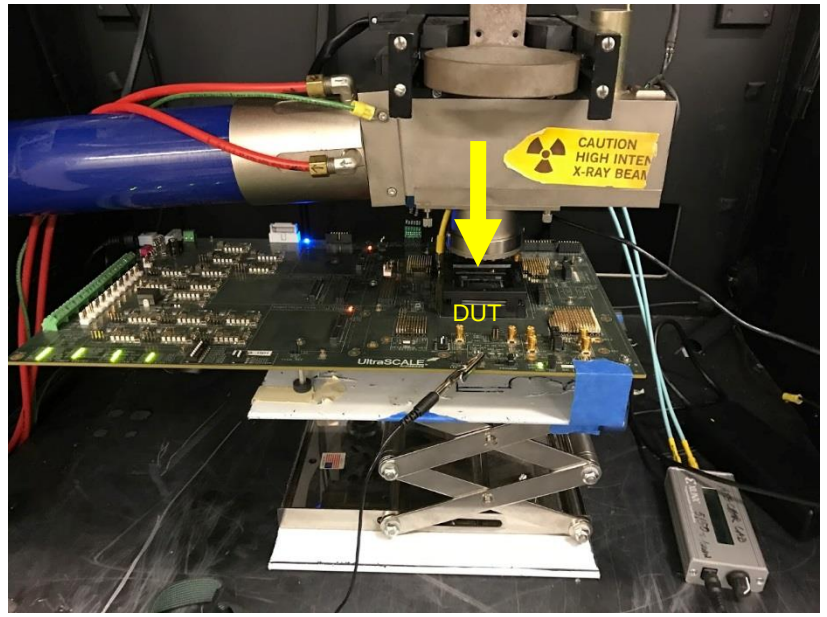
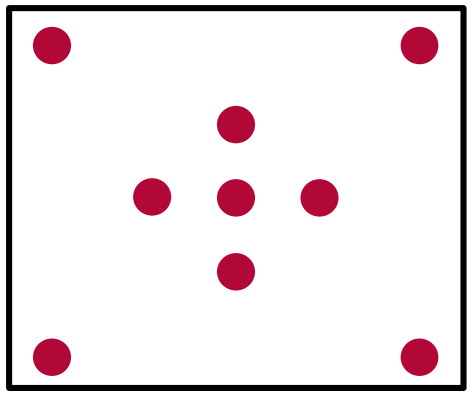
X-Ray TID Test Set-Up

- 10 keV X-Ray used as proxy for ^{60}Co Gamma TID
  - Aracor system @ Vanderbilt University
- Test Detail
  - Parts thinned to 40 μm; X-Ray exposure from die backside
  - Total exposure to 150 kRad
    - Dose rates of 5 kRad /min & 10 kRad /min
  - Equivalency to ^{60}Co Si dose level
    - 140 kRad (SiO^2) X-Ray ≈ 100 kRad (Si) ^{60}Co gamma rays
    - Hence correction factor of 0.73 used to derive ^{60}Co Si gamma dose
- Currents monitored using Maxim power tool GUI
- Ring oscillators used to characterize real-time performance
  - 9 ring oscillators across die; 4 in corners and 5 in center
  - Typical RO frequency ~ 300 MHz



Ring oscillators distribution on DUT for performance characterization



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